ACTIVE MEMBERS TO ESTABLISH ON-ORBIT MODAL DATA FOR MODAL CORRELATION

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ABSTRACT

The paper presents an approach to experimentally determine the modal sensitivity derivatives with respect to physical parameters of a structure in space or on the ground. The information experimentally validates the Jacobian used to update the analytical model to correlate with the experimental modal data. The approach is applicable to Adaptive Structures and utilizes active members. For verification of the approach, numerical simulations of a 4.5 meter diameter truss structure and experimental verification plan and progress are presented.

NOMENCLATURE

{DF}	vector of difference between the test and initial mathematical eigenfunctions
[dF/dP]a	matrix of derivative of the mathematical eigenfunction with respect to the physical structural parameter P.
[dF/dP]e	vector of experimental change in eigenfunction with respect to the physical structural parameter P.
{P}	vector of the physical structural parameters, such as area or thickness, to be updated.
{DP}	vector of difference between the initial estimate of P and the updated P to minimize {DF}.

1. INTRODUCTION

For many space applications, the requirement is for accurate analytical structural dynamic models representing the flight hardware. To improve the mathematical model, modal tests of the structure are performed and the mathematical model is then updated to obtain the best correlation with the test data. Mathematical models are developed because the requirements are for modal characteristics of many configurations, including launch and on-orbit, and multi-configuration modal tests are expensive and often impractical. For the launch configuration, the need is for structural loads throughout the structure that are obtainable from the mathematical model but impractical to experimentally measure. Tests of on-orbit configurations can be more complicated because of the structural interaction of the hardware with gravity and the atmosphere. Recent controls-structures experiments [1] indicate the performance and stability of the controls system are highly dependent upon the knowledge of the structural dynamic characteristics. This observation is especially valid for precision (submicron) large structural systems (20-30 meters in dimensions) with high modal density (10-50 modes of interest) and very low (≤ .1%) damping.

Significant activities in modal tests for ground testing and modal. updating approaches exist. Current ground modal test and modal updating approaches [2] will not meet some of the future requirements. On-orbit modal testing and model updating approaches promise to help meet future requirements. One approach to help meet the challenges is to introduce robustness into the design for structural dynamics. Taguchi and Clausing states that " robustness of products is more a function of good design than of on-line control however stringent" the analysis or testing. Robustness can be achieved by designing the capability for the structure to adapt itself to have the desired dynamics during its operation in space.

This paper reviews the role of Adaptive Structures to introduce robustness into the structural design. An important phase in the use of Adaptive Structures approach is to perform on-orbit system identification to measure the dynamics of the system for model update in its operational configuration. Active members as excitation sources for on orbit modal testing, and the novel approach by which experimental sensitivity values required for model updating approaches are feasible when Adaptive Structures are incorporated into the design. The experimentally obtained sensitivity information provides more accurate information, thus improve the model updating. Simulations are on a 4.5 meter diameter truss shown in Figure 1 and tests to verify the simulations are in progress.

2. ADAPTIVE STRUCTURES

Adaptive Structures are systems whose geometric and physical structural characteristics can be beneficially modified to meet mission requirements wither through remote commands or automatically in response to internal or external stimulations [3,4]. The incorporation of Adaptive Structures in the design increases the "robustness" of the design that helps meet the future challenges of precision space structures by:

- Improving the reliability of its deployment/assembly,
- helping to validating the structural system by ground test,
- reliably meeting the precision structural requirements during its 20-30 lifetime, and
- adding redundancy to the mechanical system.

Adaptive Structures can substantially reduce cost and schedule and are thus applicable to both large and small structures.

An important part of Adaptive Structures are active members that are incorporated into the structural system. Active members directly integrates the actuators and sensors into the load carrying structural element that is electronically control to meet the objectives. In the near future, miniaturized electronics will be available to integrate them into the structure itself. Many different designs of actuators currently exists [5].

One of the initial JPL active member design is shown in Figure 2. For this configuration, both piezoelectric and electrostrictive actuators are incorporated into the design. The sensors include a non-contact displacement sensors that measures the relative displacement of the two ends of the active member and a load cell to measure the load in the member. The resolution of the displacement sensor is down to 2 nanometers and the actuator is submicron. By proper phasing of the actuator, the active member can be used to excite the structure, introduce active damping, and increase or soften the active member stiffness. These features have been successfully demonstrated in the laboratory [4].

The potential of Adaptive Structures have excited many researchers and funding agencies, resulting in many new researchers, papers, journals, and conferences. The Fourth International Conference on Adaptive Structures was recently held in Cologne, Germany [6].

3. MODAL TESTING

Modal test procedures used for ground testing are not necessarily transferable to on-orbit modal testing or system identification. The excitation source are frequently mounted to the ground or suspended during the ground tests. Active members incorporated into the Adaptive Structure for vibration control are ideally located to provide force excitations corresponding to anticipated amplitude levels. The location is ideal because the active members are located at locations of maximum strain energy of the modes for control and thus can easily excite the modes of interest. Unlike placing exciters at locations of maximum displacement, active members provides force in the proper direction at locations where the modal forces are high to achieve proper modal force distribution. Force excitation providing the proper modal force distribution eliminates many discrepancies previously noted and should give a more accurate estimate of modal damping. Previous modal tests results were dependent on the direction of force excitation at a node. Modal damping contributions are from slippage at joints that are a function of the force magnitude through the joints and thus the modal force distribution.

Successful modal tests using active members for both fixed and free-free structures are in References [7,8]. Results of one modal test [7] are shown in Figure 3.

4. MODEL UPDATING

Most model updating procedures depend on the successful solution of equations similar to

$$\{DF\} = [dF/dP]a\ \{DP\}. \qquad (1)$$

The Jacobian [dF/dP]a is then inverted to obtain {DP} which establishes the modifications to the structural parameter P resulting in the "best" correlation of the mathematical model to the test data. The novel approach of this paper is to obtain an experimental estimate of the Jacobian. The experimental estimate of the Jacobian is obtained by increasing or decreasing the stiffness of each of the active members, one at a time. At each change, another active member is used as an excitation source without changing its stiffness and the modal parameters F are experimentally measured. When the change in modal parameters Fi are experimentally determined for a change in one value of Pi, the rate of change are the experimental estimates of the i column of the Jacobian. Thus by repeating the process for other active members, the mathematical estimates of the Jacobian can be replaced by experimental measurements.

With Adaptive Structures, the experimental estimates of the Jacobian can be easily implemented at the beginning of the mission using existing exciters, sensors, and power required to meet mission requirements.

The numerical simulation is on the 4.5 meter diameter truss shown in Figure 1 since it is a truss available at JPL to experimentally validate the approach. The truss is a precision structure fabricated with "tight" joints to hold micron level tolerances. Previous experiments have been performed successfully to adjust the dimensions to micron levels and to add active damping using active members.

5. CONCLUSION

The reports summarizes the potential benefits of Adaptive Structures for both large and small spacecraft and the use of active members for both modal testing and model updating. Adaptive Structures increases the robustness of the design that promises to improve performance while reducing cost and schedule. The proposed novel approach of experimental determination of the Jacobian for model updating may significantly improve the ability to obtain accurate mathematical models. The approach is easily adaptable to on-orbit system identification that may become mandatory to meet future space requirements. The concepts are applicable to other mechanical and civil systems and are currently under study.

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